

**A systematic literature review to evaluate the tools and methods used to measure rein tension.**

Dumbell, Lucy; Lemon, Chloe; Williams, Jane

*Published in:*

Journal of Veterinary Behavior: Clinical Applications and Research

*Publication date:*

2019

*The re-use license for this item is:*

CC BY-NC-ND

*This document version is the:*

Peer reviewed version

*The final published version is available direct from the publisher website at:*  
[10.1016/j.jveb.2018.04.003](https://doi.org/10.1016/j.jveb.2018.04.003)

**[Find this output at Hartpury Pure](#)**

*Citation for published version (APA):*

Dumbell, L., Lemon, C., & Williams, J. (2019). A systematic literature review to evaluate the tools and methods used to measure rein tension. *Journal of Veterinary Behavior: Clinical Applications and Research*, 29.  
<https://doi.org/10.1016/j.jveb.2018.04.003>

## 1    ***Introduction***

2    The modern horse is predominantly regarded as a companion or sporting animal  
3    in Western Europe with high profile equestrian events accounting for at least half  
4    of the top ten sporting events in the UK in 2016 and 2017 with paid for  
5    attendance (Deloitte, 2016, 2017). In 2015 the equestrian sector was responsible  
6    for £4.3 billion of consumer spending in Great Britain alone (BETA, 2017). To  
7    maintain this consumer interest and attract new audiences the future of  
8    equestrianism is reliant on the public's perception of the sport (Fletcher and  
9    Dashper, 2013). As such presenting the horse and human as a team, with both  
10   members athletes, is important to counteract long held perceptions of  
11   equestrianism epitomising social inequality and elitism with the horse being an  
12   expensive 'tool' to achieve success (Krishna and Haglund, 2008).

13

14   There have been recent high profile questions around the welfare of the horse  
15   and the safety of the human during sporting performance and associated  
16   training, such as the occurrence of rotational falls (injuring both the horse and the  
17   rider) in eventing and blood in the saliva of dressage horses (Jones, 2017;  
18   Bryan, 2017). Decision makers within equestrian sport are therefore required to  
19   cultivate techniques which minimise risks to human and equine athletes, and  
20   maximise efforts to ensure equine welfare is a top priority in sporting and training  
21   environments (FEI, 2017a). Central to achieving safe interaction and harmony  
22   between horse and human is understanding how the two species can  
23   communicate. As well as having socio-economic implications for the future of

24 equestrian sport, this topic is central to the field of Equitation Science (FEI,  
25 2017b; International Society for Equitation Science, 2017).

26

27 There is still a paucity of evidence-based practice and objective performance  
28 analysis measures underpinning practices commonly undertaken in  
29 equestrianism (Cornelisse, 2001; Williams, 2013) despite the potential  
30 improvements in competitive success these can facilitate. To address this  
31 researchers are increasingly trying to utilise perceived objective measures of the  
32 horse-human interaction to assess how the horse and rider can perform together,  
33 rather than focussing on the horse and rider separately (Clayton and Hobbs,  
34 2017; Randle and Waran, 2017). As the only Olympic sport where two species  
35 compete in partnership (De Haan and Dumbell, 2016) the complexity of studying  
36 equestrian sport should not be underestimated. Technology can be used to  
37 measure horse-human interactions with the aim of producing objective  
38 parameters to define and assess if riding and training practices promote equine  
39 welfare / wellbeing (Williams, 2013; Randle *et al.*, 2017). Data obtained can also  
40 be used to advance equestrian performance analysis by understanding what  
41 expert equestrians do and producing models that less experienced equestrians  
42 can train towards reproducing, an approach that is fundamental to sport  
43 technique analysis (Lees, 2002). However for both of these outcomes to be  
44 judged as accurate, reliable, precise and valid measures, data need to have  
45 been collected using validated research equipment. It is also important that a  
46 standardised research framework and experimental protocols are applied across  
47 studies to enable worthwhile comparison to be made between projects and to

48 develop an objective evidence base for advancing equitation practice  
49 (Cornelisse, 2001; Pierard *et al.*, 2015; Randle *et al.*, 2017).  
50  
51 An emerging area of investigation is the interface between the horse and the  
52 rider, with communication between the rider's hands and the horse's bit  
53 commonly evaluated by rein tension as a proxy measure of the resulting forces.  
54 Rein tension is defined as the force exerted along the reins via a mouthpiece or  
55 'bit' in the horse's mouth, as an aid to control direction, speed and head position  
56 of the horse and is typically measured in Newtons (N) (Clayton *et al.* 2003). The  
57 bit and the (rein) tension applied on it are fundamental in horse-rider  
58 communication and control during ridden and in-hand training (McGreevy and  
59 McLean, 2007; McGreevy, 2007; McLean and McGreevy, 2010; Hawson *et al.*,  
60 2014). Behavioral responses of horses originate from neurological motivation to  
61 avoid pain, discomfort and predation (McGreevy, 2007) and it is common  
62 practice for animal trainers to make use of such innate responses and to provide  
63 rewards for desired behaviors. Rewards can take the form of praise or negative  
64 reinforcement involving the removal of an aversive stimulus such as pressure  
65 etc. (Terada *et al.*, 2006; McGreevy and Boakes, 2006). Precisely timed pressure  
66 signals from the rider are transferred through the reins to the horse to control the  
67 direction and speed at which the horse travels, and the position of its head and  
68 neck carriage. It is the timing of these pressure signals and particularly the timing  
69 of the release of pressure that is an important determinant of their success  
70 (Heleski *et al.*, 2009; Manfredi *et al.*, 2010).

71

72 The application of 'excessive' rein tension during equestrianism is central to  
73 debates on rein tension and equine welfare amongst equine professionals  
74 (McLean and McGreevy, 2010; ISES, 2017). Inadequate timing of rein signals or  
75 unintentional pulls on the reins have been identified to cause poor welfare and a  
76 negative stress response in the horse (Waran and Randle, 2017) and can result  
77 in the exhibition of undesirable or conflict behaviors (McLean and McLean 2002;  
78 Heleski *et al.*, 2009; Manfredi *et al.*, 2010; McLean and McGreevy, 2010), which  
79 may then result in rider injuries (Newton and Neilson, 2005). In addition to this,  
80 standard equipment worn by horses such as bits and nosebands, are designed  
81 to reduce the extent that horses can physically exhibit undesirable behaviors,  
82 which may be associated with uncomfortable or excessive bit pressure  
83 (McGreevy *et al.*, 2005; Randle and McGreevy, 2013). Being able to measure the  
84 forces exerted by the rider and experienced by the horse, especially if evidence-  
85 based ranges of acceptable rein tension can be produced, would enable  
86 objectively based interventions to be made to improve horse welfare and rider  
87 training and ultimately reduce the risk of horses demonstrating potentially  
88 dangerous behaviors.

89

90 The development of technology capable of measuring the forces associated with  
91 differing rein tensions has led to an emergence of research in recent years  
92 measuring rein tension. This technology is rapidly being commercialised to make  
93 it accessible to all levels of equestrian however this raises concerns as to  
94 whether it is supported by reliable, evidence-based research (Randle *et al.*,  
95 2017). This study uses a systematic literature review to evaluate the tools and

96 methods currently used to measure rein tension within published literature to  
97 establish whether their findings were reliable. The systematic literature review  
98 also aimed to identify improvements to study protocols, where appropriate, to  
99 enable the standardised measurement of rein tension to be used to inform  
100 decision makers, commercial developments and good practice guidance in the  
101 future

102

### 103 ***Materials and Methods***

104

105 A systematic literature review uses explicitly stated search methods determined  
106 by a panel of subject specialists and library professionals to systematically  
107 approach a literature review and reduce the inherent bias in any literature search  
108 (Centre for Reviews and Dissemination, 2001; Sargeant *et al.*, 2006; Dundar and  
109 Fleeman, 2014; Gough et al. 2017). The search strategy employed for this  
110 systematic literature review was determined by a panel including two  
111 independent academic professionals who have published in the area of  
112 performance analysis within equestrianism, a librarian for assistance in  
113 identifying relevant databases, and a Fellow of the British Horse Society to  
114 provide an industry perspective, in addition to the researchers to centre the  
115 research aims (Dundar and Fleeman, 2014). The panel defined the search  
116 method including keywords, literature sources and inclusion criteria and decided  
117 that 'Google Scholar' should be the search engine used due to the breadth of  
118 material that it contains. This review adapted inclusion criteria (Table 1) from the  
119 Cochrane Participants, Interventions, Comparisons, Outcomes and Study Types

120 guidelines (Higgins and Green, 2011). The decision to include literature over a  
121 fifteen year period, resulted from discussions with the subject specialists during  
122 the search strategy development process to reduce the risk of the search being  
123 inadvertently influenced by author convenience issues, a common literature  
124 review bias (McCrae *et al.*, 2015). Much of the investigation of rein tension has  
125 resulted from the field of Equitation Science that has been the focus of the  
126 International Society of Equitation Science since it was founded in 2007 and first  
127 proposed in 2002 (ISES, 2018).. Inclusion of literature from a fifteen year period  
128 also aligned with these noteworthy dates.

129

130 The purpose of the current systematic review was to analyse all available rein  
131 tension literature, regardless of human or equine demographics and therefore  
132 strict participant criteria were not required. No exclusions to the number of  
133 participants, their age, nor methods of quantitative data collection were  
134 implemented (Maber-Aleksandrowicz *et al.*, 2016). A comprehensive evaluation  
135 of full papers was deemed necessary by the panel of subject specialists in order  
136 to meet the research objectives of this review. Abstract only and non-peer  
137 reviewed publications (including student theses) were excluded due to the  
138 reported lack of consistency between abstracts and full papers in the reporting of  
139 results (Snedeker *et al.*, 2010), and the lack of independent professional  
140 appraisal in the scientific quality of the work produced (Lee *et al.*, 2012). Only  
141 English language papers were included within this review to ensure that the  
142 content was not misreported due to inaccurate translation. Whilst rejection of  
143 results due to language barriers is not recommended in systematic reviews,

144 Smith *et al.* (2011) acknowledged a lack of accessible translation services as a  
145 reasonable cause for the rejection of papers. When a language inclusion criterion  
146 is applied it is considered best practice to report how many potential papers were  
147 excluded for language reasons, and this approach was adopted within the  
148 current study (Smith *et al.*, 2011)

149

150 Data extraction was conducted by the review team; an inductive content analysis  
151 was adopted from Keegan et al. (2014) performed utilizing tags ('open-coding') to  
152 create themes ('focused coding') which were then organized to demonstrate their  
153 relationship to key areas within rein tension research, study characteristics, rein  
154 tension devices, participant characteristics and outcomes related to measured  
155 rein tension. To strengthen the review an iterative consensus validation process  
156 was conducted by the authors to ensure tags were placed under appropriate  
157 themes and a peer debrief was undertaken to debate the validity and reliability of  
158 the results obtained (Dundar and Fleeman, 2014; O'Connor and Sargeant,  
159 2015).

160

## 161 **Results**

162

163 A search of the keywords across full articles on 'Google Scholar' returned 154  
164 initial search results. Of those 154 results 12 publications were rejected as they  
165 were not available in the English language. A further 115 publications were  
166 rejected including: equine studies unrelated to the review (72), non-equine  
167 studies (18), equine reviews (19) and books (6). A further five studies were



168 rejected at this point because abstracts were published without access to the full  
169 study. Figure 1 illustrates the study selection process by flow diagram. As a  
170 result of the selection process, seventeen primary research papers (post 2001)  
171 were selected for review.

172

### 173 *Study Characteristics*

174 The study characteristics in the seventeen studies selected for final review varied  
175 (Table 2). Even studies that appear similar differ in important characteristics.  
176 Heleski *et al.* (2009) examined changes in behavior and rein tension in four  
177 horses with and without martingales; thus investigating rein tension, behavior and  
178 riding equipment. Egenvall *et al.* (2012) similarly focused on equine behavior and  
179 rein tension in four horses, however, in this study behavioral observations were  
180 related to rider influences (two methods of trot-walk transitions) rather than the  
181 horse's behavior associated with use of riding equipment as in Heleski *et al.*  
182 (2009).

183

184 Studies utilised three main genres of rein tension intervention: (1) ridden, (2) non-  
185 ridden or (3) mixed interventions. Methodologies within the main genres varied  
186 and investigated the relationship of one (or more) variable(s) and their  
187 association with rein tension. Sub-themes included: equine behavior, equine  
188 welfare and rider influence/performance, with a small amount of literature also  
189 testing riding equipment such as bits and leatherwork. A total of eleven studies  
190 focused on ridden rein tension, four on non-ridden rein tension and two better  
191 suited a mixed category including both ridden and non-ridden measures.

192

193 Rein tension was investigated as a secondary measure to the primary focus in 24  
194 % of reviewed studies. This resulted in incomplete measures in some cases, for  
195 example Eisersiö *et al.* (2013) did not record rein tension for 80% of the study  
196 population (n=15).

197

#### 198 *Rein Tension Devices*

199 There were variations in the rein tension devices utilized across the studies in  
200 this review (Table 3). All seventeen studies named which device they used,  
201 although variations included: 'strain gauge transducers,' 'ReinCheck™,' 'custom  
202 made Inertial Measurement Units (IMU),' 'Futek' and 'SMA mini S-beam force  
203 gauges.' Differences in the sensitivity of tension measurements and maximum  
204 load capacities were reported between devices and should be considered in the  
205 comparison of results accordingly (Eisersiö *et al.*, 2015). For example, the strain  
206 gauge transducer used by Clayton *et al.* (2005) had a maximum load of 2002 N  
207 which exceeds the maximum range of 500 N in the custom made IMU used by  
208 both Eisersiö *et al.* (2015) and Egenvall *et al.* (2015 and 2016), and the 50 N  
209 maxima of the ReinCheck™ system (Kuhnke *et al.*, 2010; Egenvall *et al.*, 2012;  
210 Christensen *et al.*, 2014). A number of limitations were reported with the  
211 ReinCheck™ including its inability to accurately record peak rein tension due to  
212 insufficient maximal capacity (Christensen *et al.*, 2014) and there were also two  
213 reports of kit failure in this system (Egenvall *et al.*, 2012; Von Borstel and  
214 Glibman, 2014). Overall, studies presented device specifications inconsistently

215 and 18 % of studies failed to report the maximum load capacities of their devices  
216 (Manfredi *et al.*, 2005; Eisersiö *et al.*, 2013; Cross *et al.*, 2016).

217

218 The majority of studies (88 %) recorded rein tension bilaterally. The exceptions to  
219 this were case studies by Clayton *et al.* (2005) and Cross *et al.* (2016) where  
220 unilateral left and right rein tensions were investigated respectively. These  
221 studies tested pioneering equipment during riding; either generic rein tension  
222 (Clayton *et al.*, 2005) or more recently Cross *et al.* (2016) created a dual-force  
223 measuring device, which measured tension exerted on the reins and the cheek-  
224 piece of the bridle (to quantify poll-pressure).

225

#### 226 *Participant characteristics*

227 There was a lack of consistency in how participant characteristics were reported  
228 across the studies reviewed for human and equine participants (Table 4). The  
229 majority of studies (94 %) included some details of participant characteristics,  
230 except Cross *et al.* (2016), who reasoned participant information was not  
231 required in the study. The majority (87 %) of reviewed studies used both equine  
232 and human participants and the remaining two studies (13 %) either used equine  
233 or human participants. However, only 41 % of studies included descriptive  
234 demographics for both the equine and human participants (41 %). The detail of  
235 the participants' descriptions was also variable with less detail often reported  
236 about the equine participants.

237

238 The literature reviewed represented 203 equine participants across seventeen  
239 studies, a mean ( $\pm$  s.d.) of 12 ( $\pm$  12.0) (Table 4). Within individual studies, the  
240 sample size utilised ranged between 1 and 46 horses. Sample sizes of less than  
241 10 horses were used in 59 % of studies, 18 % included 11 to 20 horses and 23 %  
242 used more than 21 horses. Equine demographic information were provided by 88  
243 % of studies. These reported a range of variables including age, breed, sex,  
244 height, weight and training experience, although not all were described in every  
245 study. Age (range: 2-18 yrs), breed (variable) and sex (24 geldings, 66 mares, 18  
246 stallions) of the horses were reported in 71 %, 47 % and 41 % of the literature  
247 respectively. In contrast horse height (range: 1.45 -1.70 m) and weight (range:  
248 392 -586 kg) were only recorded in 18 % of studies respectively. Equine training  
249 experience and the discipline the horse was being trained for were included in  
250 the majority of studies (76 %). The majority of the reviewed studies measured  
251 rein tension in older, experienced horses. Where specified, the most common  
252 discipline investigated appeared to be dressage, although horses within this  
253 discipline were trained from preliminary level up to Grand-Prix. Only  
254 Christensen *et al.* (2011) used young horses naïve to biting.

255

256 A total of 101 human participants were included across the seventeen studies,  
257 encompassing 98 riders and 3 handlers, a mean ( $\pm$  s.d.) of 16 ( $\pm$  4.9) (Table 4).  
258 Individual study populations of human participants were smaller than equine  
259 study populations ranging from one to fifteen participants. Twenty nine % of  
260 studies involved a single participant, 41 % of studies included 3 to 9 participants  
261 and 30 % had greater than 10 participants. Human demographics were stated in

262 the majority of the reviewed studies although 29 % of studies failed to include  
263 further details of the human participants beyond stating the sample size used  
264 (Manfredi *et al.*, 2005; Manfredi *et al.*, 2010; Clayton *et al.*, 2011; von Borstel and  
265 Glibman, 2014; Cross *et al.*, 2016). The consistency of what variables were  
266 included between the studies was poor. For example, level of rider experience  
267 (novice to Grand Prix), weight (range: 56 – 95 kg), height (range: 1.59 -1.8 m),  
268 sex, human handedness and age (range 14 - 50 years) of riders were reported in  
269 59 %, 35 %, 29 %, 24 %, 18 % and 12 % of studies, respectively.

270

#### 271 *Data Collection*

272 The preparation of equipment is a key stage in reporting data collection protocols  
273 but calibration was only reported in twelve of the seventeen studies. Five studies  
274 (Manfredi *et al.*, 2005; Warren-Smith *et al.*, 2007; Kuhnke *et al.*, 2010; Manfredi  
275 *et al.*, 2010; Cross *et al.* 2016) did not refer to this critical stage. Across the  
276 studies sampling rates varied, with ranges between 100 Hz (Christensen *et al.*,  
277 2011; Egenvall *et al.*, 2012), 140 Hz (Eisersio *et al.*, 2013) and 240 Hz (Clayton  
278 *et al.*, 2011; Heleski *et al.*, 2009) reported.

279

280 Data handling between reviewed studies was inconsistent (Table 5). Forces are  
281 usually reported in Newtons. Although Kuhnke *et al.* (2010) reported rein tension  
282 in kilograms Force (kgF) these data can be converted using a simple equation  
283 (formula:  $XX\text{kg} \times 9.81 = \text{N}$ ) to enable comparisons to be made. Rein tension data  
284 processing was only reported in four papers (Clayton *et al.*, 2005; Heleski *et al.*,

285 2009; Clayton *et al.*, 2011; Cross *et al.*, 2016) with the Butterworth filter being the  
286 most commonly utilised.

287

288 Some studies reported the main findings as *peak* rein tensions i.e. the maximum  
289 that was recorded (Clayton *et al.*, 2005; Eisersiö *et al.*, 2013; Egenvall *et al.*,  
290 2015, 2016). In contrast, others based their conclusions on *average* rein tension  
291 (Warren-Smith *et al.*, 2007; Heleski *et al.*, 2009; Kuhnke *et al.*, 2010; Christensen  
292 *et al.*, 2011; Eisersiö *et al.*, 2015).

293

## 294 **Discussion**

295

296 There was unanimous agreement across the reviewed studies that individual  
297 horse and rider characteristics significantly influence rein tension. However,  
298 authors suggested different influencing characteristics including the horse, the  
299 rider or equipment, or a combination of the three factors; consequently, no  
300 specific aetiology to explain variation in rein tension has been proposed to date  
301 (Figure 2). Nevertheless, the general consensus reported that rein tension  
302 increased with the gait of the horse, increasing from 6.9 - 43 N in walk to 10.8 -  
303 51 N in trot and 1.5 - 104 N in canter (Clayton *et al.*, 2005; Kuhnke *et al.*, 2010;  
304 Eisersiö *et al.*, 2015; Egenvall *et al.*, 2016).

305

306 In addition to changes in gait, increased tensions could be related to training  
307 practices where horses are taught to yield at higher pressures (McLean and  
308 McLean, 2002), or the threshold where bit pressure becomes excessive could

309 have increased due to habituation i.e. desensitisation (McLean and McGreevy,  
310 2010; Christensen *et al.*, 2011). Learning theory recommends training self-  
311 carriage during locomotory responses without habituation to pressure signals  
312 (McLean and McGreevy, 2015). If the horse is trained to accept more pressure in  
313 the mouth, it could increase the risk of injury, negatively affect equine welfare,  
314 and perpetuate the need for increasingly stronger pressures. The horse's  
315 individual training may also determine whether undesirable behavior is  
316 associated with increasing rein tension (Warren-Smith *et al.*, 2007; Christensen  
317 *et al.*, 2011).

318

319 Manfredi *et al.* (2010) found a significant increase in undesirable behavior  
320 indicative of increased equine stress levels as rein tension was progressively  
321 increased. The study used six different bits, representing bits considered by  
322 industry to have a mild through to severe action (McGreevy *et al.*, 2005; Randle  
323 and Wright; 2013). Interestingly individual bit type demonstrated no association  
324 with undesirable behaviors (Manfredi *et al.*, 2010) perhaps suggesting it is how  
325 the bit is used and learning theory is applied within this use, which could trigger  
326 the expression of conflict behaviors. A wide range of bits are available for use in  
327 horses, with reported actions on different parts of the horse's head potentially  
328 affected to different extents by increasing rein tension. Technological advances  
329 now permit dual-force rein tension measurements that quantify rein vs. poll  
330 pressure and offer insights into actual bit mechanism (Cross *et al.*, 2016). As a  
331 result, rein tension could be used to design equipment based on scientific  
332 evidence.

333

334 *Rein tension and head and neck position*

335 Equine head and neck position can be influenced by riders and the use of  
336 training aids (Clayton *et al.*, 2011; Eisersiö *et al.*, 2013; Egenvall *et al.*, 2015).  
337 Studies (ridden and non-ridden) agreed that as rein length becomes shorter,  
338 measured rein tension and the frequency of evasive behavior increases (Clayton  
339 *et al.*, 2011; Eisersiö *et al.*, 2013; Christensen *et al.*, 2014). However, research  
340 suggests rein material and noseband tightness may also significantly affect rein  
341 tension (Randle *et al.*, 2011; Randle and McGreevy, 2013). However, with the  
342 exception of Warren-Smith *et al.* (2007) where length, weight and thickness of  
343 material was reported, the majority of ridden studies in the review failed to  
344 include specific details on rein type.

345

346 Similarly, studies in the review inconsistently reported noseband tightness or  
347 type. For example, Eisersiö *et al.* (2013) reported horses wore standard bridles,  
348 some wore cavesson nosebands and some flash nosebands. Additional research  
349 reported that when cavesson nosebands were fitted loosely greater rein tensions  
350 were measured than when fitted tightly (Randle and McGreevy, 2013). To date,  
351 the effect of flash nosebands on rein tension have not been investigated. Flash  
352 nosebands are designed to restrict the horse from opening the mouth (Casey *et al.*,  
353 2013) comparing horses subjected to different noseband conditions is likely  
354 to yield incomparable rein tension data. To confirm the relationship between rein  
355 length, horse head and neck position, and measured rein tension, future



356 research should include description of noseband type and tightness, and rein  
357 type, material, length and weight.

358

### 359 *Rein tension and the participants*

360

361 The riders used across the research reviewed were all experienced equestrians,  
362 able to anticipate locomotory movements and remain in synchronisation with the  
363 horse (Terada *et al.*, 2004; LaGarde *et al.*, 2005). Riders with previous  
364 experience may have preconceptions about socially desirable equitation  
365 practices and therefore minimise the force they exert on the reins (Terada *et al.*,  
366 2004; Heleski *et al.*, 2009). The prevalence of the ‘participant effect’ is  
367 reasonably high in experimental studies causing test participants to  
368 subconsciously alter their behavior and respond in a way they assume the  
369 researcher expects (Nichols and Maner, 2008). Therefore rein tension research  
370 may not represent riders outside studies or beginner riders (McLean and  
371 McGreevy, 2010). The fact however that rein tension was not the primary focus  
372 of four studies may actually be beneficial here and reduce this ‘participant effect’.

373

374 Only 13% of studies reported human handedness preferences although these  
375 saw bilateral rein tension asymmetries during turning manoeuvres and transitions  
376 with the non-dominant hand applying higher rein tension than the dominant hand  
377 (Kuhnke *et al.*, 2010; Hawson *et al.*, 2014; Eisersiö *et al.*, 2015). Laterality  
378 preferences are reported to increase grip strength by up to 10% on the dominant  
379 side of the body in the majority of the general population (Steele, 2000; Oppewal

380 *et al.*, 2013) which could explain the bilateral asymmetries observed. Where  
381 handedness bias was reported, the studies predominantly used right-handed  
382 participants reflecting the majority of the human population (Faurie *et al.*, 2012).  
383 Equine sidedness is the equivalent of human handedness and as rein tension is  
384 derived from both horse and human a study investigating the interaction between  
385 human handedness and equine sidedness would increase understanding of rein  
386 tension. These two factors should be consistently reported in rein tension  
387 studies.

388

389 Given rein tension derives from human and equine interaction few studies  
390 included descriptive demographics for both the equine and human participants  
391 (41 %) and the detail of that reporting was highly variable. Clear reporting of the  
392 characteristics of both human and equine participants in a published study is  
393 essential to enable the reader to understand the limits to the validity of the  
394 findings. Pierard *et al.* (2015) outlined an extensive list of factors that should be  
395 included in equitation research and its key features are applicable to research  
396 measuring rein tension. These factors can be grouped into three groups, horse-  
397 related, rider-related and performance-related factors. For rein tension research  
398 they should also include handedness preferences in rider-related factors and  
399 tack descriptions in horse-related factors. Figure 3 displays the factors that  
400 should be reported in future rein tension research.

401

402 *Study design*

Care should be taken to avoid forming false-positive assumptions from the results of studies that cannot be generalised to the wider population (Hackshaw, 2008; Holmes and Jeffcott). This is a serious concern in equestrian research, where identifying large samples that share sufficient characteristics to be considered similar is difficult and sourcing funding for the frequently expensive data collection is often challenging. Despite this it is important that studies follow accepted study design principles to produce valid, reliable, accurate and precise results. Whilst a detailed discussion of experimental design is outside the scope of this paper Randle *et al.* (2017) provides an accessible overview.

The purpose of case studies is to investigate single-units with the aim to generalize across a larger set of units (Gerring, 2004). Therefore, the findings of Clayton *et al.* (2005) and Cross *et al.* (2016) do not model causal relationships i.e. the cause of rein tension, but aim to define the case, i.e. to infer what happens during rein tension, and as case studies the results obtained are only applicable to the subjects under investigation.

#### *Data collection, processing and analysis*

Rein tension gauges tend to sit between the bit and the reins, and as such are not an absolute measure of the force acting upon the horse's mouth. For studies focussing on the horse's experience it would be better to measure the pressure experienced by the horse. Pressure is the force acting upon a defined area, therefore the size of the area that the pressure acts upon will influence the magnitude and effect observed. Future rein tension studies should consider this

427 within their design and report rein tension as a force in Newtons, or ideally a  
428 pressure in  $\text{Nm}^{-2}$ . Future research could utilise pressure sensitive film or fabric to  
429 determine how rein tension relates to what the horse is experiencing on the lips,  
430 the bars of the mouth, the poll and other anatomical areas (Pierard *et al.*, 2015).

431

432 Experimental studies should aim to demonstrate reproducibility and as such  
433 report their materials and methods in a detailed manner, including giving precise  
434 descriptions of equipment used (Randle *et al.*, 2017). Inconsistencies in reporting  
435 create barriers to developing a generic, valid and reliable approach within future  
436 rein tension research. Devices to measure rein tension should be described  
437 consistently and in detail, with manufacturer's details and product references.  
438 The maximum load capacities of devices and the levels of precision and  
439 accuracy that they are validated to provide should be clearly stated. From the  
440 studies reviewed the device must be capable of measuring forces in excess of  
441 the 104 N recorded by Clayton *et al.*, (2005). To ensure the rein tension device  
442 can perform as published it is important that it is maintained and set-up as per  
443 the manufacturer's instructions, including calibration and standardisation, as  
444 discussed in Randle *et al.* (2017). Reporting of these activities was not consistent  
445 and complete within the reviewed studies.

446

447 Rein tension data may also integrate spurious data points related to extraneous  
448 noise, therefore data processing is required to remove noise and ensure the  
449 validity and reliability of the data obtained. A number of studies documented data  
450 processing approaches undertaken (such as use of the Butterworth filter), whilst

451 others only report sampling rates and neglect to detail filtering, and how rein  
452 tension data were processed. We advocate that data processing and analysis  
453 should be reported in full as in Clayton et al. (2005), to facilitate more accurate  
454 comparison of results obtained. Reporting should include details of calibration,  
455 sampling rate and filtering protocols for rein tension data.

456

457 A consistent approach to data analysis is also recommended, within the  
458 constraints of the individual investigation and its associated hypothesis(es).  
459 There were a small number of studies which clearly presented minimum,  
460 maximum and average rein tensions providing a *holistic* understanding to  
461 measured rein tension comparable to different studies (Clayton *et al.*, 2011; Von  
462 Borstel and Glibman, 2014). Reporting solely minimum and maximum, or  
463 average rein tension is unlikely to represent true rein tension since they can  
464 easily be distorted by outliers (Tong, 2014). To improve comparability between  
465 current and future studies, the approach utilised by Clayton et al. (2011) is  
466 advocated across a minimum of 10-15 strides with due consideration of gait  
467 phasing (ideally by conducting digitally synchronised kinematic analysis). This  
468 approach measures the entirety of the force patterns which occur during different  
469 equitation movements enabling a rein tension profile to be constructed. This  
470 would support the development of reference values for optimum and excessive  
471 rein tension levels across a range of equestrian disciplines, activities and  
472 experience levels, as McGreevy (2007) advocated.

473

474 The variability in rein tension within the reviewed studies suggests it is an  
475 individualised measure. Similar patterns are observed in electromyography with  
476 reliability and consistency demonstrated within individuals rather than across  
477 cohorts (Williams et al., 2014). Future research should apply a within-subjects  
478 research framework and consider relative differences in rein tension rather than  
479 strive to identify baseline measures across horses which may not truly exist  
480 (Williams, 2018). Future research should also evaluate the impact of transitions  
481 (changes of gait) within rein tension assessment. Studies exploring pressure  
482 differentials during transitions compared to riding consistently within the gaits are  
483 warranted to fully elucidate the contribution of transitions to pressure variables  
484 commonly measured. Using kinematic analysis and rein tension assessment  
485 together would provide more accurate results and a holistic view of the role of  
486 rein tension within equitation.

487

#### 488 *Limitations of this systematic literature review*

489 The inclusion criteria rejected student theses and abstract only publications.  
490 Consequently this resulted in omission of recent research and potentially  
491 increases the effects of publication bias (Riis, 2006; Blackhall, 2007), the  
492 increased likelihood of publication for studies which find statistically 'significant'  
493 results compared to non-significant findings (O'Connor and Sargaent, 2015).

494

495 Within equestrian research small study samples are common due to the difficulty  
496 of accessing horses and riders which are managed under the same conditions  
497 (Pierard et al., 2015). The samples in the reviewed studies followed this pattern

498 and as such risk over-estimating the effect of an association (Hackshaw, 2008;  
499 Blundell, 2014).

500

## 501 **Conclusions**

502

503 The tools and methods used to measure rein tension within published literature  
504 were frequently inconsistently reported leading to difficulty in establishing  
505 whether their findings were reliable. Reporting the characteristics of the human  
506 and equine participants comprehensively, combined with using and  
507 systematically reporting robust methods of data collection, processing and  
508 analysis should support comparisons and future meta-analysis being completed.  
509 To fully understand rein tension and the effects it may have on horse and human  
510 (whether as handler or rider), larger scale studies need to be conducted.

511

512 There is a clear need for decision makers within the equine industry and  
513 research communities to consider theoretical versus actual mechanisms of  
514 standard riding equipment, in relation to rein tension. Therefore, future studies  
515 should re-focus to establish how measured rein tension equates to pressure in  
516 the equine mouth. It is important to consider the relevance of rein tension  
517 research to equestrian performance as well as equine welfare. Rein tension  
518 research will be improved by the use of consistent and robust methodologies with  
519 the aim to objectively evaluate communication between horse and human.

520

## 521 **Authorship statement**

522

523 The idea for the paper was conceived by J Williams, in discussion with C Lemon  
524 and L Dumbell

525 The experiments were designed by all, with C Lemon performing the initial  
526 search.

527 The experiments were performed by n/a

528 The data were analyzed by all

529 The paper was written by L Dumbell, with input from J Williams and C Lemon



530 **References**

- 531 British Equestrian Trade Association, 2017. Market Information. Available from:  
532 <http://www.beta-uk.org/pages/industry-information/market-information.php>  
533 [Accessed 29 April 2017]
- 534 Blackhall, K., 2007. Finding studies for inclusion in systematic reviews of  
535 interventions for injury prevention the importance of grey and unpublished  
536 literature. *Inj. Prev.* 13 (5), 359–359.
- 537 Blundell, M., 2014. Understanding and Synthesizing My Data. In: Angela (Ed)  
538 *Doing a Systematic Review A Student's Guide*. Los Angeles, CA: SAGE  
539 Publications.
- 540 Bryan, P., 2017. Three horses eliminated under blood rules at European  
541 Dressage Championships. Available from:  
542 [http://www.horseandhound.co.uk/news/three-horses-eliminated-blood-rules-](http://www.horseandhound.co.uk/news/three-horses-eliminated-blood-rules-european-dressage-championships-630320)  
543 [european-dressage-championships-630320](http://www.horseandhound.co.uk/news/three-horses-eliminated-blood-rules-european-dressage-championships-630320) [Accessed 1st December 2017]
- 544 Casey, V., McGreevy, P.D., O'Muiris, E. and Doherty, O., 2013. A preliminary  
545 report on estimating the pressures exerted by a crank noseband in the horse. *J.*  
546 *Vet. Behav.* 8 (6), 479–484.
- 547 Centre for Reviews and Dissemination, 2001. *Undertaking Systematic Reviews*  
548 *of Research on Effectiveness. CRD's Guidance for those Carrying Out or*  
549 *Commissioning Reviews*. 2nd ed. York: York Publishing Service Ltd.
- 550 Christensen, J.W., Beekmans, M., van Dalum, M. and VanDierendonck, M.,  
551 2014. Effects of hyperflexion on acute stress responses in ridden dressage  
552 horses. *Physiol. Behav.* 128, 39–45.

553 Christensen, J.W., Zharkikh, T.L., Antoine, A. and Malmkvist, J., 2011. Rein  
 554 tension acceptance in young horses in a voluntary test situation. *Eq. Vet. J.* 43  
 555 (2), 223–228.

556 Clayton, H.M. and Hobbs, S.J., 2017. The role of biomechanical analysis of  
 557 horse and rider in equitation science. *Appl. Anim. Behav. Sci.* 190, 123-132.

558 Clayton, H.M., Larson, B., Kaiser, L.J. and Lavagnino, M., 2011. Length and  
 559 elasticity of side reins affect rein tension at trot. *Vet. J.* 188 (3), 291–294.

560 Clayton, H.M., Singleton, W.H., Lanovaz, J.L. and Cloud, G.L., 2005. Strain  
 561 gauge measurement of rein tension during riding: A pilot study. *Eq. Comp. Ex.*  
 562 *Physiol.* 2 (3), 203–205.

563 Clayton, H.M., Singleton, W.H., Lanovaz, J.L. and Cloud, G.L., 2003.  
 564 Measurement of rein tension during horseback riding using strain gauges. *Exp.*  
 565 *Tech.* 27 (3), 34-36.

566 Cook, W.R., 1999. Pathophysiology of bit control in the horse. *J. Eq. Vet. Sci.* 19  
 567 (3), 196–204.

568 Cornelisse, C.J., Holcombe, S.J., Derksen, F.J., Berbey, C., Jackson, C.A., 2001.  
 569 Effect of a tongue-tie in horses during exercise. *Am. J. Vet. Res.* 62, 775–778.

570 Cross, G.H., Cheung, M.K.P., Honey, T.J., Pau, M.K. and Senior, K.-J., 2016.  
 571 Application of a dual force sensor system to characterise the intrinsic operation of  
 572 horse bridles and bits. *J. Eq. Vet. Sci.* 48, 129-135e.

573 De Haan, D. and Dumbell, L., 2016. Equestrian Sport at the Olympic Games  
 574 from 1900 to 1948. *Int. J. Hist. Sp.* 33 (6-7), 648-665.

575 Deloitte, 2016. Almost 70m tickets sold for UK sports events in 2016. Available  
 576 from: [https://www2.deloitte.com/uk/en/pages/press-releases/articles/70m-tickets-](https://www2.deloitte.com/uk/en/pages/press-releases/articles/70m-tickets-sold-for-uk-sports-event.html)  
 577 [sold-for-uk-sports-event.html](https://www2.deloitte.com/uk/en/pages/press-releases/articles/70m-tickets-sold-for-uk-sports-event.html) [Accessed 1st March 2018]

578 Deloitte, 2017. Almost 75m tickets sold for UK sports events in 2017. Available  
 579 from: [https://www2.deloitte.com/uk/en/pages/press-releases/articles/almost-75m-](https://www2.deloitte.com/uk/en/pages/press-releases/articles/almost-75m-tickets-sold-for-uk-sports-events-in-2017.html)  
 580 [tickets-sold-for-uk-sports-events-in-2017.html](https://www2.deloitte.com/uk/en/pages/press-releases/articles/almost-75m-tickets-sold-for-uk-sports-events-in-2017.html) [Accessed 1st March 2018]

581 Dundar, Y. and Fleeman, N., 2014. Developing my search strategy and applying  
 582 my inclusion criteria. In: Boland, A., Cherry, M.G. and Dickson, R., (Ed), Doing a  
 583 Systematic Review A Student's Guide. London: SAGE Publications Ltd, pp. 35–  
 584 60.

585 Egenvall, A., Eisersjö, M. and Roepstorff, L., 2012. Pilot study of behavior  
 586 responses in young riding horses using 2 methods of making transitions from trot  
 587 to walk. *J. Vet. Behav.* 7 (3), 157–168.

588 Egenvall, A., Roepstorff, L., Eisersjö, M., Rhodin, M. and Van Weeren, R., 2015.  
 589 Stride-related rein tension patterns in walk and trot in the ridden horse. *Acta Vet.*  
 590 *Scand.* 57–89.

591 Egenvall, A., Roepstorff, L., Rhodin, M., Eisersjö, M. and Clayton, H.M., 2016.  
 592 Maximum and minimum peaks in rein tension within canter strides. *J. Vet. Behav.*  
 593 13, 63–71.

594 Eisersjö, M., Rhodin, M., Roepstorff, L. and Egenvall, A., 2015. Rein tension in 8  
 595 professional riders during regular training sessions. *J. Vet. Behav.* 10 (5), 419–  
 596 426.

597 Eisersiö, M., Roepstorff, L., Weishaupt, M.A. and Egenvall, A., 2013. Movements  
 598 of the horse's mouth in relation to horse–rider kinematic variables. *Vet. J.* 198,  
 599 e33–e38.

600 Faurie, C., Llaurens, V., Hegay, T. and Raymond, M., 2012. Handedness and  
 601 socioeconomic status in an urban population in Uzbekistan. *Evol. Hum. Behav.*  
 602 33 (1), 35–41.

603 FEI, 2017a. Code of Conduct for the Welfare of the Horse. Available from:  
 604 [http://inside.fei.org/system/files/Code\\_of\\_Conduct\\_Welfare\\_Horse\\_1Jan2013.pdf](http://inside.fei.org/system/files/Code_of_Conduct_Welfare_Horse_1Jan2013.pdf)  
 605 [Accessed 29th April 2017]

606 FEI, 2017b. FEI Values. Available from: <http://inside.fei.org/fei/about-fei/values>  
 607 [Accessed 29th April 2017]

608 Finneran, A. and O'Sullivan, L., 2013. Effects of grip type and wrist posture on  
 609 forearm EMG activity, endurance time and movement accuracy. *Int. J. Ind.*  
 610 *Ergon.* 43 (1), 91–99.

611 Fletcher, T. and Dashper, K., 2013. 'Bring on the dancing horses!': Ambivalence  
 612 and class obsession within British media reports of the Dressage at London  
 613 2012. *Sociol. Res. Online.* 18 (2). DOI: 10.5153/sro.3040

614 Gough, D., Oliver, S. and Thomas, J., 2017. Introducing systematic reviews. In  
 615 Gough, D., Oliver, S. and Thomas, J. (Eds.), *An Introduction to Systematic*  
 616 *Reviews.* (pp. 1-16). 2<sup>nd</sup> ed. London: SAGE Publications Ltd, pp. 1–16.

617 Gough, D., Thomas, J. and Oliver, S., 2012. Clarifying differences between  
 618 review designs and methods. *Syst. Rev.* 1 (1), 28.

619 Greenhalgh, J., Bagust, A., Boland, A., Martin Saborido, C., Oyee, J., Blundell,  
 620 M., Dundar, Y., Dickson, R., Proudlove, C. and Fisher, M., 2011. Clopidogrel and

621 modified-release dipyridamole for the prevention of occlusive vascular events  
 622 (review of technology appraisal no. 90): A systematic review and economic  
 623 analysis. *Health Technol. Assess.* 15 (31).  
 624 Hackshaw, A., 2008. Small studies: Strengths and limitations. Editor. 1  
 625 November. Available from:  
 626 <http://erj.ersjournals.com/content/32/5/1141doi:10.1183/09031936.00136408>  
 627 [Accessed 24 February 2016].  
 628 Hawson, L.A., Salvin, H.E., McLean, A.N. and McGreevy, P.D., 2014. Riders'  
 629 application of rein tension for walk-to-halt transitions on a model horse. *J. Vet.*  
 630 *Behav.* 9 (4), 164–168.  
 631 Heleski, C.R., McGreevy, P.D., Kaiser, L.J., Lavagnino, M., Tans, E., Bello, N.  
 632 and Clayton, H.M., 2009. Effects on behaviour and rein tension on horses ridden  
 633 with or without martingales and rein inserts. *Vet. J.* 181 (1), 56–62.  
 634 Higgins, J.P.T. and Green, S., 2011. *Cochrane Handbook for Systematic*  
 635 *Reviews of Interventions Version 5.1.0.* Chichester, England: Wiley-Blackwell.  
 636 Hinnemann, J., van Baalen, C., van Andel, C., Bronkhorst, A. and Caremans, D.,  
 637 2004. *The Simplicity of Dressage.* United States: Trafalgar Square.  
 638 Holmes, M. and Jeffcott, L., 2010. Equitation Science, rider effects, saddle and  
 639 back problems in horses: can technology provide the answer? *Vet. J.* 184 (1), 5-  
 640 6.  
 641 International Society of Equitation Science, 2017. ISES Mission and Aims.  
 642 Available from <http://equitationscience.com/> [Accessed 29<sup>th</sup> April 2017]  
 643 International Society of Equitation Science, 2018. About ISES. Available from  
 644 <http://equitationscience.com/> [Accessed 1<sup>st</sup> March 2018]

645 Jakovljevic, D.G. and McConnell, A.K., 2009. Influence of different breathing  
 646 frequencies on the severity of Inspiratory muscle fatigue induced by high-  
 647 intensity front crawl swimming. *J. Strength Cond. Res.* 23 (4), 1169–1174.  
 648 Jones, E., 2017. French event rider dies after rotational fall. Available from  
 649 [http://www.horseandhound.co.uk/news/eventer-maxime-debost-dies-rotational-](http://www.horseandhound.co.uk/news/eventer-maxime-debost-dies-rotational-fall-633119#brVIJqJLfQdfYTfu.99)  
 650 [fall-633119#brVIJqJLfQdfYTfu.99](http://www.horseandhound.co.uk/news/eventer-maxime-debost-dies-rotational-fall-633119#brVIJqJLfQdfYTfu.99) [Accessed 10<sup>th</sup> October 2017]  
 651 Knicker, A.J., Renshaw, I., Oldham, A.R.H. and Cairns, S.P., 2011. Interactive  
 652 processes link the multiple symptoms of fatigue in sport competition. *Sp. Med.* 41  
 653 (4), 307–328.  
 654 Krishna, A. and Haglund, E., 2008. Why do Some Countries Win More Olympic  
 655 Medals? Lessons for Social Mobility and Poverty Reduction. *Econ. Political*  
 656 *Weekly.* 43, 145.  
 657 Kuhnke, S., Johnson, J.L., Gauly, M., Borstel, U.K. von, Dumbell, L. and  
 658 McDonald, K., 2010. A comparison of rein tension of the rider's dominant and  
 659 non-dominant hand and the influence of the horse's laterality. *Comp. Ex. Physiol.*  
 660 7 (02), 57–63.  
 661 Lagarde, J., Peham, C., Licka, T. and Kelso, J.A.S., 2005. Coordination  
 662 dynamics of the horse-rider system. *J. of Mot. Behav.* 37 (6), 418–424.  
 663 Lee, C.J., Sugimoto, C.R., Zhang, G. and Cronin, B., 2012. Bias in peer review.  
 664 *J. Am. Soc. Info. Sci. Tech.* 64 (1), 2–17.  
 665 Lees, A., 2002. Technique analysis in sports: a critical review. *J. of Sports Sci.*  
 666 20, 813-828.  
 667 Ludewig, A.K., Gauly, M. and von Borstel, K.U., 2013. Effect of shortened reins  
 668 on rein tension, stress and discomfort behavior in dressage horses. *J. Vet.*  
 669 *Behav.* 8 (2), e15–e16.

670 Maber-Aleksandrowicz, S., Avent, C. and Hassiotis, A., 2016. A systematic  
 671 review of animal-assisted therapy on psychosocial outcomes in people with  
 672 intellectual disability. *Res. Dev. Disabil.* 49-50, 322–338.

673 Manfredi, J., Clayton, H. and Rosenstein, D., 2005. Radiographic study of bit  
 674 position within the horse's oral cavity. *Eq. Comp. Ex. Physiol.* 2 (3), 195–201.

675 Manfredi, J.M., Rosenstein, D., Lanovaz, J.L., Nauwelaerts, S. and Clayton,  
 676 H.M., 2010. Fluoroscopic study of oral behaviours in response to the presence of  
 677 a bit and the effects of rein tension. *Comp. Ex. Physiol.* 6 (04), 143–148.

678 McCrae, N., Blackstock, M. and Purssell, E., 2015. Eligibility criteria in systematic  
 679 reviews: A methodological review. *Int. J. Nurs. Stud.* 52 (7), 1269–1276.

680 McGreevy, P.D., 2007. The advent of equitation science. *Vet. J.* 174 (3), 492–  
 681 500.

682 McGreevy, P.D. and Boakes, R.A., 2006. Carrots and sticks: Principles of animal  
 683 training. Cambridge: Cambridge University Press.

684 McGreevy, P.D. and McLean, A.N., 2007. Roles of learning theory and ethology  
 685 in equitation. *J. Vet. Behav.* 2 (4), 108–118.

686 McGreevy, P.D. and Rogers, L.J., 2005. Motor and sensory laterality in  
 687 thoroughbred horses. *Appl. Anim. Behav. Sci.* 92 (4), 337–352.

688 McGreevy, P., McLean, A., Warren-Smith, A., Goodwin, D., Waran, N. and  
 689 Botterill, S., 2005. ISES Australia2005 proceedings [online]. Available from:  
 690 [http://www.equitation-science.com/documents/Proceedings/Australia2005\\_Procee](http://www.equitation-science.com/documents/Proceedings/Australia2005_Proceedings.pdf)  
 691 [dings.pdf](http://www.equitation-science.com/documents/Proceedings/Australia2005_Proceedings.pdf) [Accessed 12 March 2016].

692 McLean, A.N. and McGreevy, P.D., 2010. Horse-training techniques that may  
 693 defy the principles of learning theory and compromise welfare. *J. Vet. Behav.* 5  
 694 (4), 187–195.

695 McLean, A. and McGreevy, P., 2015. ISES training principles poster 2015.  
 696 Available from:  
 697 [http://www.equitation-science.com/documents/Equitation/ISES\\_Training\\_Principles](http://www.equitation-science.com/documents/Equitation/ISES_Training_Principles_Poster_2015.pdf)  
 698 [s\\_Poster\\_2015.pdf](http://www.equitation-science.com/documents/Equitation/ISES_Training_Principles_Poster_2015.pdf) [Accessed 11 March 2016].

699 McLean, A. and McLean, A., 2002. Horse training the Mclean way: The science  
 700 behind the art. Victoria: Australia Equine Behaviour Centre.

701 Meade, M.O. and Richardson, W.S., 1997. Selecting and appraising studies for a  
 702 systematic review. *Ann. Intern. Med.* 127 (7), 531.

703 Murphy, J. and Arkins, S., 2008. Facial hair whorls (trichoglyphs) and the  
 704 incidence of motor laterality in the horse. *Behav. Process.* 79 (1), 7–12.

705 Newton, A.M. and Nielsen, A.M., 2005. A review of horse-related injuries in a  
 706 rural Colorado hospital: Implications for outreach education. *J. Emerg. Nurs.* 31  
 707 (5), 442–446.

708 Nichols, A.L. and Maner, J.K., 2008. The good-subject effect: Investigating  
 709 participant demand characteristics. *J. Gen. Psych.* 135 (2), 151–166.

710 O'Connor, A. and Sargeant, J., 2015. Research synthesis in veterinary science:  
 711 Narrative reviews, systematic reviews and meta-analysis. *Vet. J.* 206 (3), 261–  
 712 267.

713 Oppewal, A., Hilgenkamp, T.I.M., van Wijck, R. and Evenhuis, H.M., 2013. The  
 714 effect of handedness on grip strength in older adults with intellectual disabilities.  
 715 *Res. Dev. Disabil.* 34 (5), 1623–1629.



716 Pierard, M., Hall, C., Borstel, U.K. von, Averis, A., Hawson, L., McLean, A.,  
 717 Nevison, C., Visser, K. and McGreevy, P., 2015. Evolving protocols for research  
 718 in equitation science. *J. Vet. Behav.* 10 (3), 255–266.  
 719 Pinker, S., 2007. Steven Pinker - toward a Consilient study of literature -  
 720 philosophy and literature 31: 1. *Philos. Lit.* 34, 1.  
 721 Pugh, T.J. and Bolin, D., 2004. Overuse injuries in equestrian athletes. *Curr.*  
 722 *Sports Med. Rep.* 3 (6), 297–303.  
 723 Randle, H. and McGreevy, P., 2013. The effect of noseband tightness on rein  
 724 tension in the ridden horse. *J. Vet. Behav.* 8 (2), e18–e19.  
 725 Randle, H. and Wright, H., 2013. Rider perception of the severity of different  
 726 types of bits and the bitless bridle using rein tensionometry. *J. Vet. Behav.* 8 (2),  
 727 e18.  
 728 Randle, H. and Waran, N., 2017. Breaking down barriers and dispelling myths:  
 729 the need for a scientific approach to Equitation. *Appl. Anim. Behav. Sci.* 190, 1-4.  
 730 Randle, H., Abbey, A. and Button, L., 2011. The effect of different rein types on  
 731 the rein tension applied when taking up a 'medium contact'. *J. Vet. Behav.* 6 (5),  
 732 295.  
 733 Randle, H., Steenbergen, M., Roberts, K. and Hemmings, A., 2017. The use of  
 734 the technology in equitation science: A panacea or abductive science? *Appl.*  
 735 *Anim. Behav. Sci.* 190, 1-4.  
 736 Riis, J., 2006. *Cochrane handbook for systematic reviews of interventions 4.2.6*  
 737 [online]. Available from: [http://community-](http://community-archive.cochrane.org/sites/default/files/uploads/Handbook4.2.6Sep2006.pdf)  
 738 [archive.cochrane.org/sites/default/files/uploads/Handbook4.2.6Sep2006.pdf](http://community-archive.cochrane.org/sites/default/files/uploads/Handbook4.2.6Sep2006.pdf)  
 739 [Accessed 13 March 2016].

740 Sandberg, J. and Alvesson, M., 2010. Ways of constructing research questions:  
 741 Gap-spotting or problematization? *Organ.* 18 (1), 23–44.  
 742 Sargeant, J.M., Rajic, A., Read, S. and Ohlsson, A., 2006. The process of  
 743 systematic review and its application in agri-food public-health. *Prev. Vet. Med.*  
 744 75 (s 3–4), 141–151.  
 745 Slingerland, E. and Collard, M., 2011. *Creating Consilience: Integrating the*  
 746 *sciences and the humanities.* United States: Oxford University Press.  
 747 Smith, V., Devane, D., Begley, C.M. and Clarke, M., 2011. Methodology in  
 748 conducting a systematic review of systematic reviews of healthcare interventions.  
 749 *BMC Med. Res. Method.* 11 (1), 15.  
 750 Snedeker, K.G., Campbell, M., Totton, S.C., Guthrie, A. and Sargeant, J.M.,  
 751 2010. Comparison of outcomes and other variables between conference  
 752 abstracts and subsequent peer-reviewed papers involving pre-harvest or  
 753 abattoir-level interventions against foodborne pathogens. *Prev. Vet. Med.* 97 (2),  
 754 67–76.  
 755 Steele, J., 2000. Handedness in past human populations: Skeletal markers.  
 756 *Laterality: Asymmetries of Body, Brain and Cognition* 5 (3), 193–220.  
 757 Terada, K., Clayton, H.M. and Kato, K., 2004. Stabilization of wrist position  
 758 during horseback riding at trot. *Eq. Comp. Ex. Phys.* 3(4), 179-184.  
 759 Tong, Z., 2014. Averages can be misleading: Try a Percentile. 23 October.  
 760 Available from: <https://www.elastic.co/blog/use-percentile> [Accessed 11 March  
 761 2016].  
 762 von Borstel, U.K. and Glißman, C., 2014. Alternatives to conventional evaluation  
 763 of rideability in horse performance tests: suitability of rein tension and

764 behavioural parameters. PLoS ONE. 9(1). e87285. doi:  
 765 10.1371/journal.pone.0087285  
 766 Waran, N. and Randle, H., 2017. What we can measure, we can manage: The  
 767 importance of developing robust welfare indicators for use in Equitation. Appl.  
 768 Anim. Behav. Sci. 190, 74-81.  
 769 Warren-Smith, A.K., Curtis, R.A., Greetham, L. and McGreevy, P.D., 2007. Rein  
 770 contact between horse and handler during specific equitation movements. Appl.  
 771 Anim. Behav. Sci. 108 (s 1–2), 157–169.  
 772 Williams, D.E. and Norris, B.J., 2007. Laterality in stride pattern preferences in  
 773 racehorses. Anim. Behav. 74 (4), 941–950.  
 774 Williams, J., 2018. Electromyography in the horse: a useful technology. J. Eq.  
 775 Vet. Sci. 60, 43-58e2.  
 776 Williams, J., 2013. Performance analysis in equestrian sport. Comp. Ex. Physiol.  
 777 9 (2), 67-77.  
 778 Williams, J.M., Johnson, C., Bales, R., Lloyd, G., Barron, L., Quest, D., 2014.  
 779 Analysis of Temporalis and Masseter adaptation after routine dental treatment in  
 780 the horse via surface electromyography. Comp. Ex. Physiol. 10 (4), 223-232.  
 781

782

783 Figure 1: Flow diagram of the study selection process for key words 'rein tension'

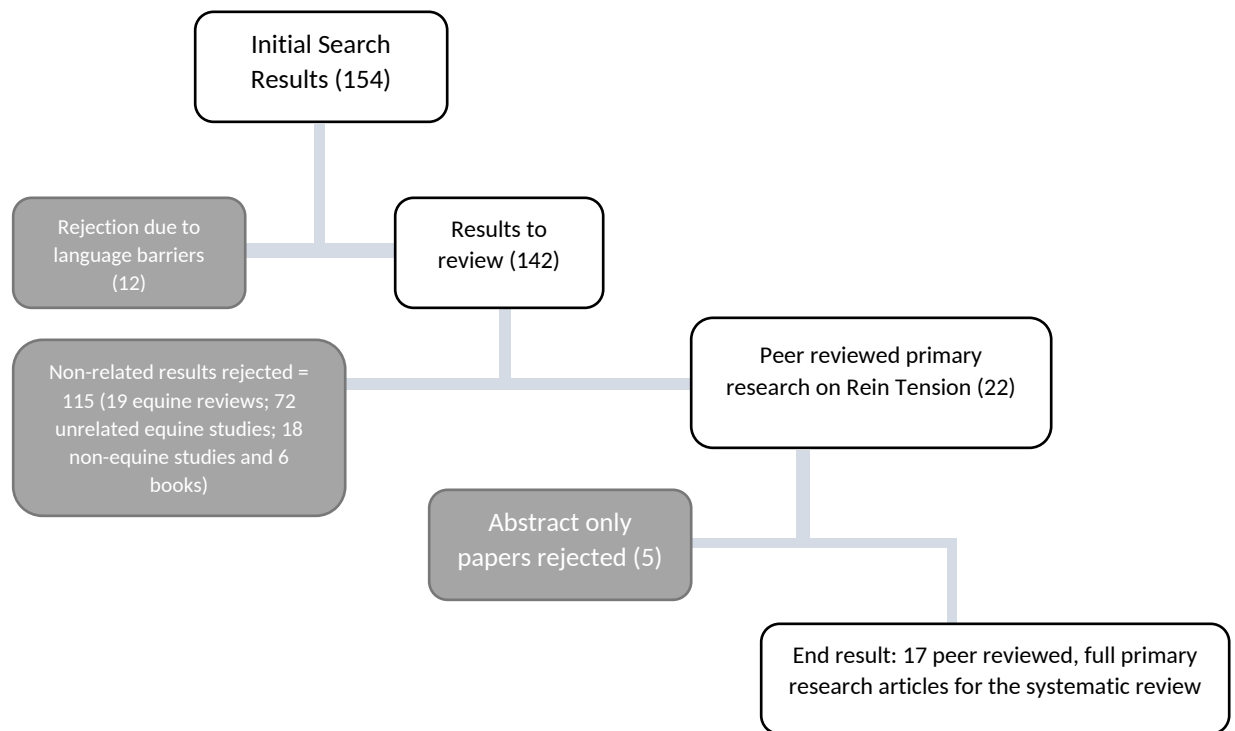
784 AND 'horse/s' OR 'rider/s' OR 'equine/s' OR 'equestrian', in Google Scholar

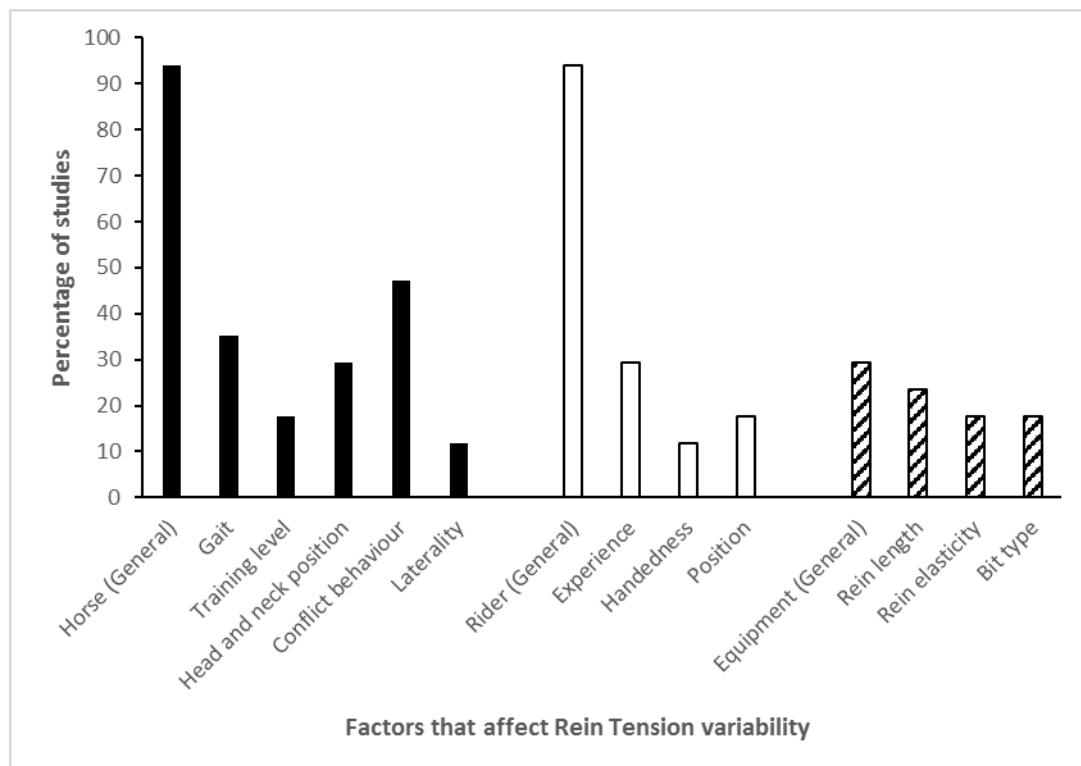
785 (>2001) = 154

786

787

788





789

790 Figure 2 Incidence of factors which are associated with rein tension variability  
 791 reported by the seventeen reviewed studies.

792

793

794 Tif heading submitted as a separate file:

795 Figure 3: Factors that can impact rein tension in the ridden horse. White text:

796 horse related factors; Green text: performance related factors; Yellow text: rider

797 related factors.

798

	Description	Justification
<b>Participant</b>	Equine; any breed, age, height, sex, discipline, experience. Human; all riders, all experience levels.	Expert panel & adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
<b>Intervention</b>	Rein tension; ridden and non-ridden trials	Expert panel
<b>Outcome</b>	Corresponds to reports of all recorded rein tension measurements collected via quantitative data collection. Qualitative reports from riders or observers within studies also included.	Expert panel & adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
<b>Study design</b>	Primary research; experimental studies with quantitative data collection. Peer-reviewed. Full papers (post 2001).	Adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)

800

801

802 Table 1. Inclusion criteria adapted from PICO(S) Cochrane Handbook (Higgins  
803 and Green, 2011)

804

805

Study		Study Characteristics		
		Title	Intervention/ Equipment	Method
1	Clayton <i>et al.</i> (2005)	Strain gauge measurement of RT during riding: a pilot study	Regular riding / Strain gauge transducer	[R] Walk trot and canter, both directions. Left rein measured.
2	Manfredi, Clayton & Rosenstein (2005)	Radiographic study of bit position within the horse's oral cavity	6 snaffle bits: 3 single jointed & 3 Mylers / Strain gauge transducer	[NR] Reins attached to handler via roller, 25± 5N bilaterally.
3	Warren-Smith <i>et al.</i> (2007)	Rein contact between horse & handler during specific equitation movements	Long-reining & riding / ReinCheck™	[M] RT bilaterally recorded for: turn left, turn right, going straight and halt.
4	Heleski <i>et al.</i> (2009)	Effects on behavior and RT on horses ridden with or without martingales and rein inserts	Plain reins, martingale, elastic rein inserts / ReinCheck™	[R] RT bilaterally recorded: sitting trot to walk, change of rein, walk to sitting trot
5	Manfredi <i>et al.</i> (2010)	Fluoroscopic study of oral behaviors in response to the presence of a bit and the effects of RT	3 snaffle bits: Single-jointed, KK Ultra & Myler comfort / Strain gauge transducer	[NR] Reins attached to handler via roller, 25± 5N bilaterally.
6	Kuhnke <i>et al.</i> (2010)	A comparison of RT of the rider's dominant and non-dominant hand and the influence of the horse's laterality	Rider handedness and horse laterality / ReinCheck™	[R] 3 circles of walk, sitting trot, canter, 4 halt transitions, RT recorded bilaterally. Left & right lateralized horses. Right handed riders.
7	Christensen <i>et al.</i> (2011)	RT acceptance in young horses in a voluntary situation	Degree of voluntary RT for food reward / ReinCheck™	[NR] Side reins attached to roller at: loose, intermediate and short rein length. Horse encouraged to stretch forwards to reach food reward.
8	Clayton <i>et al.</i> (2011)	Length and elasticity of side reins affect RT at trot	3 side reins at 3 lengths / Strain gauge transducer	[NR] Inelastic, stiff elastic, compliant elastic side reins attached to roller at long, neutral and short rein length. Trot in straight line with handler.
9	Egenvall <i>et al.</i> (2012)	Pilot study of behavior responses in young riding	Trot to walk transition method / ReinCheck™	[R] 1: RT relief at first attempt to perform correct response (walking). 2: RT relief at completed response.

		horses using 2 methods of making trot to walk transitions		
10	Eisersiö <i>et al.</i> (2013)	Movements of the horse's mouth in relation to horse-rider kinematic variables	Horse's HNP: 'on the bit' and unrestrained / RT meter (Futek)	[R] HNP1: loose reins, unrestrained. HNP2: neck raised, poll high, 'on the bit' as in dressage competitions. All horses and riders recorded in trot on treadmill.
11	Von Borstel and Glibman (2014)	Alternatives to Conventional Evaluation of Rideability in Horse Performance Tests: Suitability of RT and Behavioural Parameters	Behavior & RT vs Judges' evaluation of horse rideability / ReinCheck™	[M] Mare and stallion breeding station performance tests. RT and behavior measured in performance test and dressage training
12	Hawson <i>et al.</i> (2014)	Riders' application of RT for walk-to-halt transitions on a model horse	Walk to halt transition, rider handedness / ReinCheck™	[R] Model horse, built on measurements of a 155cm live horse.
13	Christensen <i>et al.</i> (2014)	Effects of hyperflexion on acute stress response in ridden dressage horses	Stress response, RT & HNP: (1) Competition frame, (2) Long Deep Round/hyperflexion, (3) loose frame / ReinCheck™	[R] Standardised 10-min DR plan in 3 HNP. Heart rate, Heart rate variability, behavior, salivary cortisol & RT recorded.
14	Eisersiö <i>et al.</i> (2015)	RT in 8 professional riders during regular training sessions	Regular riding during riding session / Custom made, IMU	[R] Rider-determined flatwork schooling session
15	Egenvall <i>et al.</i> (2015)	Stride-related RT patterns in walk and trot in the ridden horse	Stride phase related RT / Custom made, IMU	[R] Rider-determined flatwork schooling session
16	Cross <i>et al.</i> (2016)	Application of a Dual Force Sensor System to Characterise the Intrinsic Operation of Horse Bridles and Bits	Poll and rein pressure: 1 snaffle and 2 leverage bits / SMA mini S-beam force gauges	[R] Walk, trot, and canter. RT & cheek-piece measured.
17	Egenvall <i>et al.</i> (2016)	Maximum and minimum peaks in rein tension within canter strides	Stride phase related RT / Custom made, IMU, accelerometers on head and video analysis to assess head tilt and gait	[R] Rider-determined flatwork schooling session: canter through circle, lateral work and during transitions within canter.



				Influence of rider position and horse experience on RT minima and maxima measured bilaterally.
--	--	--	--	--

807

808 Table 2. Overview of included study characteristics.

809 RT=rein tension; N=Newtons; HNP= Head and Neck Position [of the horse];

810 IMU=inertial measurement unit [IMU & SMA mini S-beam force gauge & Futek

811 =rein tension devices]; R=ridden, NR=non-ridden, M= mixed interventions.

812

813

Device	Specification			Author (year)
	Maximum Load (N)	Other Factors Reported	Data sampling (Hz)	
<b>Strain gauge transducers (Transducer Technologies, Temecula, CA)</b>	2002	Weight: 85g	1000	Clayton (2005);
	-	N/A	-	Manfredi (2005);
	333	Weight: 21g	-	Heleski (2009);
	445	Weight: 21g	-	Manfredi (2010)
	333	Weight: 21g	240	Clayton (2011)
<b>ReinCheck™ (Crafted Technology, Sydney, Australia)</b>	50 or 100	Weight: 600g (data logger)	100	Warren-Smith (2007); Kuhnke (2010); Christensen (2011); Egenvall (2012); von Borstel (2014); Hawson (2014); Christensen (2014).
<b>Custom made IMU (IMU, x-io Technologies Limited, UK)</b>	500	Resolution: 0.11N	128	Eisersiö <i>et al.</i> (2015)
	500	Resolution 0.11N	128	Egenvall <i>et al.</i> (2015)
	500	Resolution 0.11N	128	Egenvall <i>et al.</i> (2016)
<b>Futek (2357 JR S-Beam mini load cell force sensor,)</b>	-	Weight: 28 g	140	Eisersiö <i>et al.</i> (2013)

<b>SMA mini S-beam force gauges (Interface, Scottsdale, Arizona)</b>	-	Calibrated to 60N (150% overload capacity)	200	Cross <i>et al.</i> (2016)
--	---	---	-----	----------------------------

815

816 Table 3. Overview of rein tension devices used in the included review studies.

817

818

Study	Participant Characteristics	
	Equine	Human
<b>Clayton <i>et al.</i> (2005)</b>	n=1 no description	n=1 rider, experienced
<b>Manfredi, Clayton &amp; Rosenstein (2005)</b>	n=8 (4-15yrs; 152-160cm; 450-586kg). 4 WB, 4 TB, basic DR training.	n=1 handler (no description)
<b>Warren-Smith <i>et al.</i> (2007)</b>	n=22 (13.1± 1.2 yrs.) 10 geldings, 4 stallions, 8 mares. Various breeds/experience	n=3 Advanced, intermediate & novice riders
<b>Heleski <i>et al.</i> (2009)</b>	n=4 (16.2± 2.1yrs) 3 geldings, 1 mare. Riding school horses.	n=9 females, novice riders (165.7± 6.2cm, 68.7± 11.3kg)
<b>Manfredi <i>et al.</i> (2010)</b>	n=6 (4–16 years; 152–161 cm; 475–523 kg) 1x Oldenburg, Trakehner, Andalusian, 3 TB. Novice level DR.	n=1 handler (no description)
<b>Kuhnke <i>et al.</i> (2010)</b>	n=2 Trakehner geldings. 19yrs, German DR level M, right lateralized. 14yrs German DR level L, left lateralized.	n=11 riders, 10 female, 1 male. 29± 15yrs 18.5±11.5yrs experience. All right handed. Trained A-M German DR level.
<b>Christensen <i>et al.</i> (2011)</b>	n=15 2yrs, mares Danish WB, naïve to bridles	NA*
<b>Clayton <i>et al.</i> (2011)</b>	n=8 (13.7 ± 2.9 yrs. 154 ± 9 cm; 484 ± 92 kg.)	n=1 handler (no description)
<b>Egenvall (2012)</b>	n=4 (3-4yrs), 2 geldings, 2 mares Swedish WB, 3-7 months ridden training	n=4 riders 1 advanced 1 intermediate, 2 novice. (167± 1.3cm; 63± 2kg),
<b>Eisersiö <i>et al.</i> (2013)</b>	n=7 (1.70± 0.07m), Warmbloods, competing at Grand-Prix/ Intermediare DR. n=3 used in RT results.	n=7 riders 3 males, 4 females (78± 17kg)
<b>Von Borstel and Glibman (2014)</b>	n=46 (n=33 mares, n=13 stallions. 3-4yrs). German Riding Horses	n=15 riders (no description)
<b>Hawson <i>et al.</i> (2014)</b>	NA*	n=12 riders 9 females, 2 males (36.8± 13.6 yrs.) 15.8± 10.1yrs riding experience. 10 right handed, 2 ambidextrous.
<b>Christensen <i>et al.</i> (2014)</b>	n=15 (5-18yrs) 7 mares, 7 geldings, 1 stallion Danish WB, Grand Prix DR level.	n=13, intermediate- Grand Prix DR
<b>Eisersiö <i>et al.</i> (2015)</b>	n=24 Advanced to basic DR training.	n=8 professional riders (173 ± 6 cm; 65.5 ± 10 kg)

<b>Egenvall et al. (2015)</b>	n=18 Advanced to basic DR training	n=6 professional riders (172 ± 8 cm; 68 ± 12 kg)
<b>Cross et al. (2016)</b>	No description	n=1 rider (no description)
<b>Egenvall et al. (2016)</b>	n=23 Advanced to young DR training. Direction of preferred bend reported.	n=8 professional riders, handedness, (173 ± 6 cm; 66 ± 10 kg)

820

821 Table 4 Overview of participant characteristics.

822 WB= Warmblood; TB=Thoroughbred; DR=dressage. Description of

823 horse/rider/handler experience taken from study description. NA\* not applicable

824 for the study

825

826

827

828

Study	Title	Results: Primary/Secondary
Clayton et al. (2005)	Strain gauge measurement of RT during riding: a pilot study	Peak RT: walk 43N; trot 51N; canter 104N. <i>Biphasic spikes in RT per stride in walk + trot and one spike in canter.</i>
Manfredi, Clayton & Rosenstein (2005)	Radiographic study of bit position within the horse's oral cavity	RT causes bit position to move in the oral cavity. <i>Movement toward premolars, under RT: Myler bits &lt; single jointed bits.</i>
Warren-Smith et al. (2007)	Rein contact between horse and handler during specific equitation movements	RT: long-reining 10.7 N > ridden movements 7.4N, P=0.025. <i>RT for halt response &gt; other movements</i> <i>P&lt;0.001</i>
Heleski et al. (2009)	Effects on behaviour and RT on horses ridden with or without martingales and rein inserts	Mean RT: plain reins and rein inserts 3.53± 0.53 N < martingales 4.10± 0.62N. Mean no. of CB exhibited per trial: martingale < plain rein < rein inserts. <i>Significant variation of CB between horses P&lt;0.0001.</i>
Manfredi et al. (2010)	Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of RT	Significant effects for 'horse X tension' but not 'horse X bit.' <i>RT applied increased time spent mouthing the bit &amp; retracting the tongue vs loose reins.</i>
Kuhnke et al. (2010)	A comparison of RT of the rider's dominant and non-dominant hand and the influence of the horse's laterality	Mean RT: walk 0.7kg < trot 1.1kg < canter 1.65kg and halt transitions 1.62kg. Significantly higher RT applied to left rein of left lateralized horse vs any rein of right lateralized horse. <i>More RT applied to outside rein when clockwise versus counter clockwise P&lt;0.05.</i>
Christensen et al. (2011)	RT acceptance in young horses in a voluntary situation	Mean RT: first day 10.2N > second day 6.0N > third day 5.7 N. Significantly more CB with shorter reins. <i>Peak RT recorded ~40N on first day.</i>
Clayton et al. (2011)	Length and elasticity of side reins affect RT at trot	Min, max, mean RT greatest in short length of all rein types, P<0.05. <i>Elasticity of reins caused minimum RT to increase and maximum RT to decrease in neutral and short rein lengths.</i>
Egenvall (2012)	Pilot study of behaviour responses in young riding	Average transition time = (1) 5.5±1.1 secs; (2) 4.4±0.7 secs. Time spent over 30N: (1) 19± 16%; (2) 38± 23%. <i>Mean RT: (1) 13.5N &lt; (2) 23N. 1 displayed fewer "pushing</i>

	horses using 2 methods of making trot to walk transitions	<i>against the bit" responses and higher frequency of decelerating behavior from the horse.</i>
<b>Eisersiö et al. (2013)</b>	Movements of the horse's mouth in relation to horse-rider kinematic variables	Peak RT: HNP1 mid stance phase; HNP2 emphasis in suspension phase, with increased lip movements and open mouth compared to stance phase. <i>HNP2: left rein tension significantly associated with increased frequency of lip and open mouth movements.</i>
<b>Von Borstel and Glibman (2014)</b>	Alternatives to Conventional Evaluation of Ride-ability in Horse Performance Tests: Suitability of RT and Behavioural Parameters	Ride-ability scores dropped with increasing mean, maximum and RT variability, $P < 0.05$ . Horse*rider effect ( $P < 0.05$ ) for mean and difference in RT indicate horse*rider pairing affects RT. <i>Mean RT differed between stations, <math>P &lt; 0.0001</math>.</i>
<b>Hawson et al. (2014)</b>	Riders' application of RT for walk-to-halt transitions on a model horse	Deceleration cue: right rein $6.24 \pm 4.1N$ < left rein $8.58 \pm 5.15N$ , $P < 0.001$ . Deceleration cue was 51% and 59% higher than resting RT for right and left reins, respectively, ( $P < 0.001$ ). <i>Left rein deceleration cue ranged 3.14-28.92N, right rein ranged 2.27-16.17N</i>
<b>Christensen et al. (2014)</b>	Effects of hyperflexion on acute stress response in ridden dressage horses	RT significantly lower ( $P < 0.001$ ) in loose frame, with less CB versus competition frame and hyperflexion, which saw significantly higher cortisol levels.
<b>Eisersiö et al. (2015)</b>	RT in 8 professional riders during regular training sessions	RT: Walk $12N$ < Trot $14-19N$ < Canter $13-24N$ . Rider position (sitting or light seat) influences RT in trot & canter.
<b>Egenvall et al. (2015)</b>	Stride-related RT patterns in walk and trot in the ridden horse	RT peaked at hind limb stance in walk & suspension phase at trot. <i>Significant difference between diagonal mid-stance phases in rising trot, not in sitting trot.</i>
<b>Cross et al. (2016)</b>	Application of a Dual Force Sensor System to Characterise the Intrinsic Operation of Horse Bridles and Bits	Snaffle bit acts in a 'pulley system' creating modest poll pressure. <i>Curb chain diverts cheek piece tension to the chin rather than the poll.</i>
<b>Egenvall et al. (2016)</b>	Maximum and minimum peaks in rein tension within canter strides	RT: Canter minima $0 - 50 N$ , mean = $8.5 \pm 8.3 N$ . maxima $1.5 - 284 N$ , mean = $56.1 \pm 33 N$ . RT higher in seated canter than 2-point seat ( $P < 0.0001$ ). Right circle had lower values than left or no circle. Maximum and minimum RT

		increased as nose moved caudally relative to poll. Young horses had highest maximum and advanced horses had highest minimum RT. Horses and riders contributed to RT.
--	--	--

830

831 *Table 5 Overview of study outcomes included in the review.*

832 RT=rein tension; CB=conflict behavior; HNP=head and neck position [of the  
833 horse]

834



